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Single Top and Top Quark Properties with CDF

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We present new results on top quark production and decay properties. These results include measurements of the transverse momentum of top quarks produced in $t\bar{t}$ events, the invariant mass of the $t\bar{t}$ system, and the W boson helicity in top quark decays. We also present limits on single top quark production for the W* and W-gluon channels.

1 Introduction

After the discovery of the top quark in 1995 [1], the CDF and D0 collaborations began the work of characterizing its production and decay properties. This summary focuses on CDF's latest results and is organized as follows. In section 2, we present limits on the two dominant single top production channels, W-gluon and W*, and discuss the prospects for studying single top production in Run II. Section 3 presents results on $t\bar{t}$ production: the top quark p_T distribution and mass of the $t\bar{t}$ system ($M_{t\bar{t}}$). In section 4, we present the results of a study on W boson helicity in top quark decays. Our conclusions are given in section 5.

2 Limits on Single Top Quark Production

The dominant mechanism for producing top quarks at the Tevatron is pair production via the strong interaction. Top quarks can also be produced singly however, through the electroweak interaction. The total cross section for single top production at the Tevatron is about half of the theoretical prediction for pair production with a top quark mass of 175 GeV/c^2. Since single top events generally have fewer jets than $t\bar{t}$ events, the number of background events is higher, making a search for single top using the Run I data samples very challenging.

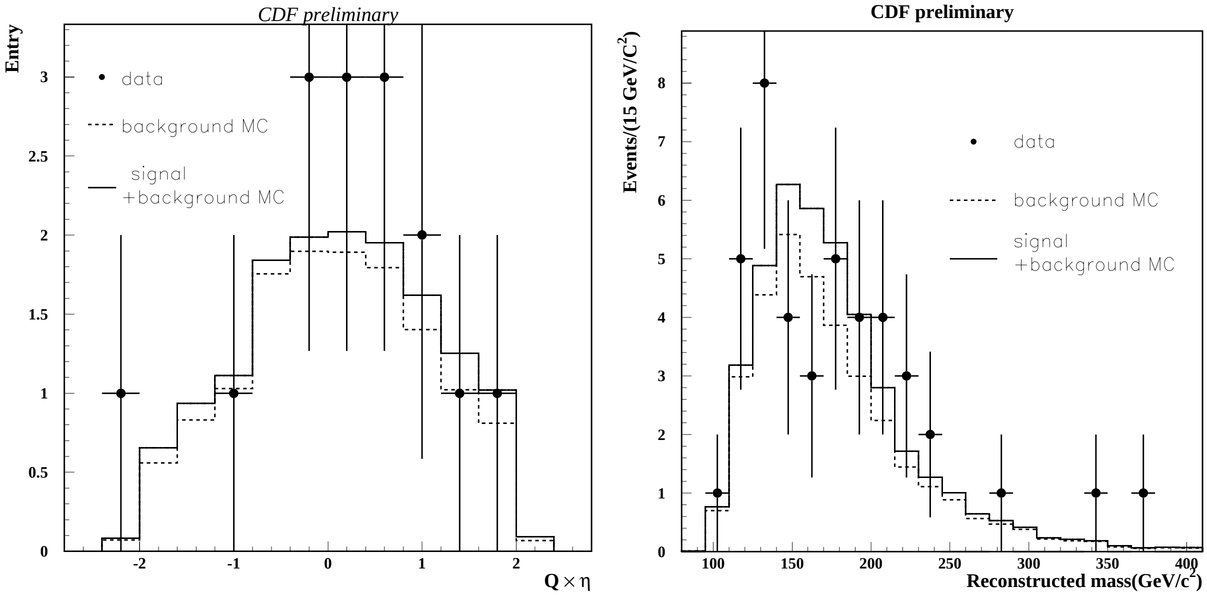

Figure 1: On the left: $Q \times \eta$ distribution for data, the W-gluon signal and backgrounds. On the right: the reconstructed top quark mass distribution for data, the W* signal and backgrounds.

2.1 The W-gluon Channel

For this single top production mechanism, a virtual b quark fuses with a virtual W boson to produce a top quark. The production cross section for this channel is ∼1.7 pb [2] .The final state consists of the decay products of the W from the top decay and two jets. One jet originates from the b quark produced in the decay of the top quark. The other jet comes from the parton that emitted the W boson involved in the production of the top quark. This jet is generally produced in the forward direction and the product of the charge of the lepton and the pseudorapidity of the jet (Q $\times\eta$) provides a very distinctive signature. To reduce backgrounds, we look for the leptonic decay products of the W boson: a lepton with $p_T > 20$ GeV/c, and missing transverse energy >20 GeV due to the undetected neutrino. We also look for two jets with E_T >15 GeV. One of the two jets is required to be tagged as a b jet using the secondary vertex algorithm (SECVTX) of CDF [3]. After these selection criteria, the main backgrounds are "W + heavy flavor" production and $t\bar{t}$ production. To reconstruct the mass of the top candidate, a W mass constraint is imposed on the decay products of the W candidate. The reconstructed top mass must lie between 145 GeV/c^2 and 205 GeV/c^2.

A binned maximum likelihood fit is performed using the Q$\times\eta$ distribution (see Figure 1). No significant excess above Standard Model background expectations is observed and we set an upper limit on the W-gluon production cross section of 15.4 pb at the 95% confidence level.

2.2 The W Channel*

In this single top channel, a quark and anti-quark produce a virtual W boson that decays to a top and b quark. The theoretical production cross section for this process is ∼0.7 pb [4]. The final state consists of two b jets and the decay products of the W. The selection criteria are identical to those described for the W-gluon channel except that there is no cut on the reconstructed top mass. Instead, a binned likelihood fit is performed on the mass distribution. Again, no significant excess above Standard Model background expectations is observed and we set an upper limit on the W* production cross section of 15.8 pb at the 95% confidence level.

Table 1: Fraction of top quarks produced in $t\bar{t}$ events with the given p_T range.

p_T Bin	Measured Fraction of Top Quarks
$0 < p_T < 75$ GeV/c	$R_1 = 0.29^{+0.18}_{-0.18}(\text{stat})^{+0.08}_{-0.08}(\text{syst})$
$75 < p_T < 150$ GeV/c	$R_2 = 0.42^{+0.18}_{-0.18}(\text{stat})^{+0.05}_{-0.07}(\text{syst})$
$150 < p_T < 225$ GeV/c	$R_3 = 0.29^{+0.12}_{-0.10}(\text{stat})^{+0.06}_{-0.05}(\text{syst})$
$225 < p_T < 300$ GeV/c	$R_4 = 0.00^{+0.04}_{-0.00}(\text{stat})^{+0.02}_{-0.00}(\text{syst})$

2.3 Prospects for Run II

In preparation for Run II, both Tevatron detectors are undergoing major upgrades. CDF is expecting significant acceptance increases for electrons and muons along with an increase in b-tagging efficiency. Extrapolating from Run I using the projected acceptance, cross section and statistics (2 fb^{-1}) increases, the uncertainty on the production cross section of single top is expected to be less than 30% with a signal significance greater than 4.

3 $t\bar{t}$ Production Properties

Some theories beyond the Standard Model predict deviations in the production properties of $t\bar{t}$ events that could be measured with Run 1 data samples at the Tevatron [5]. Two particularly sensitive variables are $M_{t\bar{t}}$ and p_T of the top quark.

3.1 Top p_T Distribution

The selection criteria for this analysis are based on CDF's top mass analysis [6] in the "lepton + jets" channel. The kinematic fitting algorithm used in the mass analysis is also used here but with the top mass constrained to 175 GeV/c^2. Due to correlations between the p_T of the two top quarks in $t\bar{t}$ events, only the hadronic-side top quark p_T is measured. The analysis evaluates the fractions of top quarks produced in four p_T bins. The fractions are corrected for detector resolution smearing and for bias introduced by the kinematic fitter. The results are presented in table 1.

The fraction of top quarks produced with a p_T between 0 and 150 GeV/c ($R_1 + R_2$) is measured to be $0.72^{+0.13}_{-0.13}(\text{stat})^{+0.06}_{-0.06}(\text{syst})$. The upper limit on the fraction R_4 (top quarks with $225 < p_T < 300$) is measured to be 0.11 at the 95% confidence level.

3.2 Mass of the $t\bar{t}$ System

A heavy particle decaying to a $t\bar{t}$ pair could reveal itself as a visible resonance in the $M_{t\bar{t}}$ distribution. This analysis also proceeds along the lines of the "lepton+jets" top quark mass analysis with the exception that top mass is constrained to 175 GeV/c^2. After this step, the top mass constraint is dropped and the fitted top mass must lie between 150 and 200 GeV/c^2. This is done to reduce the number of wrong combinations in the parton assignments determined by the kinematic fitting algorithm. No significant excess of events is observed in the $M_{t\bar{t}}$ distribution (see Figure 2).

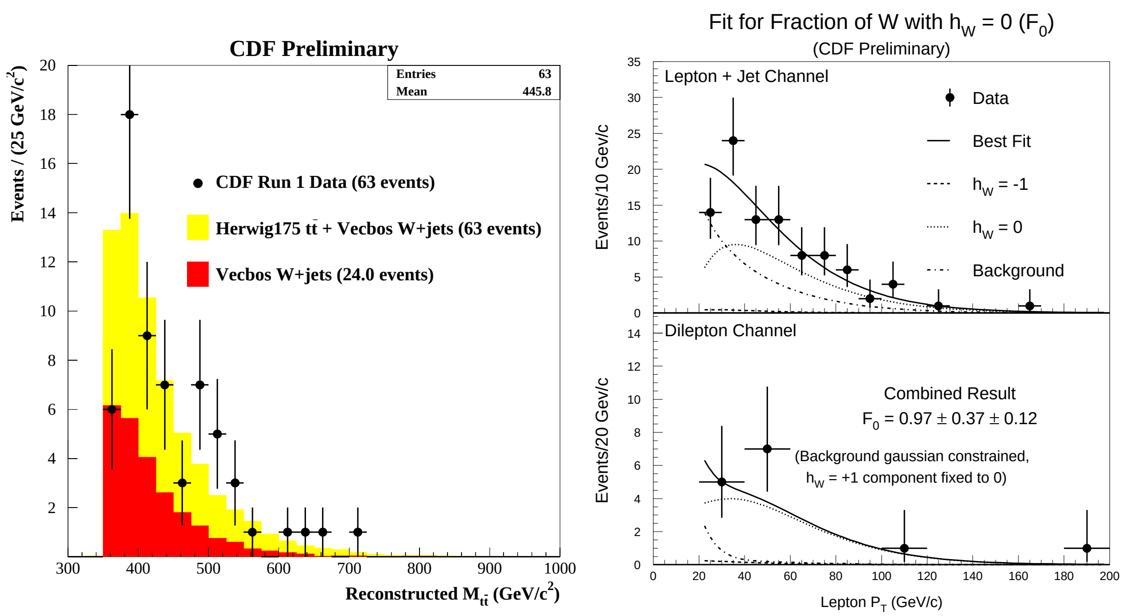

Figure 2: On the left: $M_{t\bar{t}}$ distribution for data and the expected signal and backgrounds. On the right: lepton P_T distribution used to extract the fraction of longitudinally polarized W bosons produced in top quark decay.

4 W boson helicity in top quark decays

In the Standard Model, the fraction of longitudinally polarized W bosons produced in the decay of the top quark is calculated to be ~70%, for a top quark mass of 175 GeV/c^2. The selection criteria for this analysis are those of the top mass analysis for the "lepton+jets" and dilepton analyses [7]. To extract the fraction of longitudinally polarized W bosons, a likelihood fit to the lepton p_T distribution is performed assuming no right-handed helicity contribution. The results are given in Figure 2. Likewise, to extract the right-handed helicity fraction, we assume a longitudinal fraction of 70%. The measured fraction of right-handed W bosons is 0.11 $\pm$0.15$\pm$0.06, where the first error is due to statistics and the second to systematics. Both measurements are consistent with Standard Model expectations.

5 Conclusion

The CDF and DØ collaborations have moved beyond the discovery phase and have demonstrated their ability to characterize the top quark. Run I results create a consistent picture of the top quark as a Standard Model object, but our limited statistics still leave room for surprises. We are looking forward to Run II for the observation of single top production and precision measurements of top quark properties.

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